EFFECTIVENESS OF LIME NEUTRALIZATION IN STREAM RECOVERY FROM ACID-MINE POLLUTION AS INDICATED BY SPECIES OF DIATOMS

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Abstract: At one time Slippery Rock Creek Watershed in western Pennsylvania received the effect of acid-mine drainage from approximately 1,000 coal mines. One method of reclamation tested was the establishment of a lime neutralization plant at the junction of a small, non-polluted stream and a stream experiencing heavy acid pollution. Addition of lime was employed hoping to neutralize the effect of the acid pollution on life downstream. Archibald earlier characterized the results of acid pollution on the algal flora to the level of genera in polluted and non-polluted streams in the Slippery Rock Creek Watershed. Diatoms, in particular, were selected for studying the effectiveness of lime neutralization, because of the manner in which they may be collected, and the wealth of ecological information available at the level of the species. Three sites were studied: (A) polluted stream, (B) non-polluted stream, (C) recovery area below the lime plant. Site B produced diatoms generally associated with small streams of the northeastern United States. The acid stream (A) exhibited growth of species associated with stress, those able to tolerate rapid environmental shifts in a short distance, not species regarded as hard acid stream forms. Species of Nitzchia and Navicula commonly isolated from streams in the recovery stage were found at site (C). As evidenced by collected species of diatoms, lime neutralization can be of value in helping a stream to recover from the effect of heavy acid-mine pollution.

Introduction:

Prior to concentrated efforts of acid-pollution control in the Slippery Rock Creek Watershed, Archibald (1970) and Archibald and Gentile (1971) surveyed the results of such pollution on the local algal flora to the generic level. Chlorophycean representatives were studied in detail. Later, after one of the acid-pollution control projects was in operation for sufficient time to permit measurement of its effectiveness, a second project was undertaken. Diatoms were selected as indicator organisms, because of the manner in which they may be collected and the wealth of ecological information available as to species density and population structures. Archibald conducted the field collections and studied those algal flora other than diatoms. Christensen identified all diatoms and collected known ecological data. Both authors contributed to summarizing the results as reported in this paper.

Selection of Study Site:

At one time the Slippery Rock Creek Watershed in western Pennsylvania received the effect of acid-mine drainage from approximately 1,000 coal mines. One method of reclaimation being tested is lime neutralization of streams experiencing heavy acid-pollution before they flow into non-polluted streams. A plant for this purpose was built 7 miles northeast of Harrisville, Pennsylvania, in Butler County. At this point a small stream heavily polluted with acid wastes enters the headwaters of the North Branch of Slippery Rock Creek before the North Branch flows into the main stream just below Boyers, Pennsylvania.

Slide collection boxes were placed in 3 stream sites (Fig 1) on the lime plant's property so that continuous collections of material could be made. Collection boxes not on state protected property usually are destroyed by local inhabitants.

Site A. Acid-pollution stream prior to entry into storage lagoon for lime neutralization treatment. The pH[1] varies from 4.0 -5.5 depending on the rate of surface run-off and pattern of water flow; bottom is rocky; stream shallow, usually 1-2 ft with a slight flow. Neither insect larvae or minnows are able to survive.

Site B. North Branch of Slippery Rock Creek prior to entry of acid-polluted stream. The pH varies from 6.8-7.2; bottom is rocky; stream is 3-4 ft deep with ripple areas; the stream is free of acid-pollution and supports insect larvae and minnows.

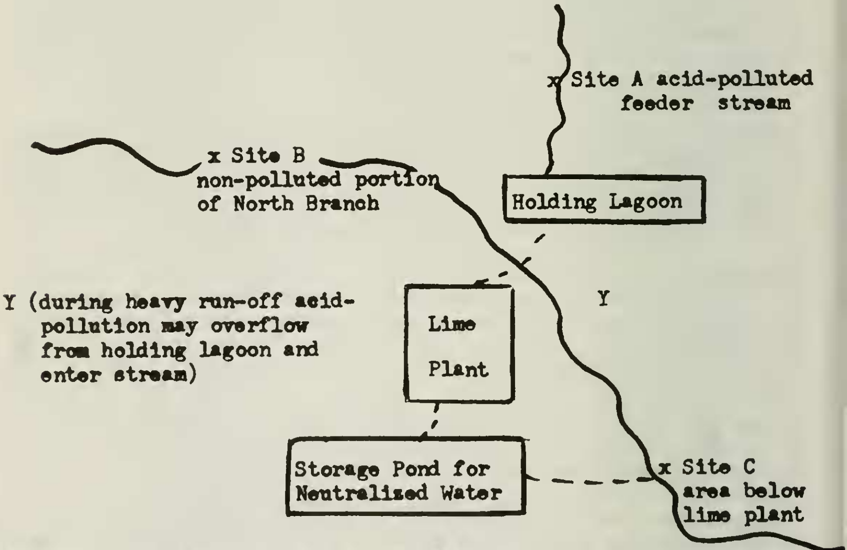

Figure 1. Collection Sites on Lime Neutralization Plant Property.

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[1] pH readings supplied by the lime plant personnel from the plant's instruments during the investigation were averaged.

Site C. 25 ft below the introduction of lime neutralized water from the treatment plant. The pH varies from 7.5-8.2; bottom is rocky; stream is 3-4 ft deep with ripple areas; both insect larvae and minnows are found in the stream.

Materials and Methods:

Wooden slide boxes with holes drilled to permit water flow were fitted with clean, untreated glass microscope slides. A box was fastened at each collection site so that it was submerged in a ripple area. Slides were collected every 2 weeks from Oct. 15 to Nov. 19, 1971. Slides collected in the field were placed immediately in a covered slide container so that they were not touching. Slides were transported in this manner to the laboratory and then shipped at a later date to Christensen.

The slides were air dried for several weeks and then weighed to determine the biomass of each slide. The five-slide groups from each collection station were then cleaned using the modified Van Der Werff hydrogen peroxide-potassium dichromate method (Christensen, 1971). To complete the cleaning process the material from each group was boiled in nitric acid for 20 minutes (Patrick and Reimer, 1966). The cleaned material was placed on # 1 cover slips, air dried and mounted in Hyrax on microscope slides. A slide was selected from each collection for use in identification and counting. Relative abundance was determined by completing 5,000 to 10, 000 counts on each selected slide under oil immersion.

At different times during the collection period, extensive matts of euglenophycean and chlorophycean filaments appeared on the site bottoms and rocks. Samples of material from the matts were placed in stream water in an uncovered container and immediately transported to the laboratory for identification. Such material also was plated onto inorganically enriched agar plates for maintaince of growth during study in the laboratory.

Results and Discussion:

Growth of phytoplankton in freshwater streams usually is dominated by unicellular chlorophycean genera (Archibald, 1970; Archibald and Gentile, 1971). This growth, however, is not apparent unless a bloom of a specific species occurs. A few species, particularly filamentous forms, may produce dense matts of growth on the stream's floor.

During late summer and fall pronounced matts of growth appeared in all three stream sites. The heavily polluted stream (Site A) had a mixed growth of the filamentous Oedocladium lewisii Whitford and Euglena intermedio (Klebs) Schmutz. Most of the bottom growth was of E. intermedio, a species which has been reported from various habitats (Whitford, 1969). Archibald and Gentile (1971) found that unicellular green algae comprise most of the algal flora during the late summer. Filamentous forms are more common during the spring.

Site B, the "typical" northeastern woodland stream displayed a thick, lush growth of Microspora amoena (Kutz) Rabenhorst on the

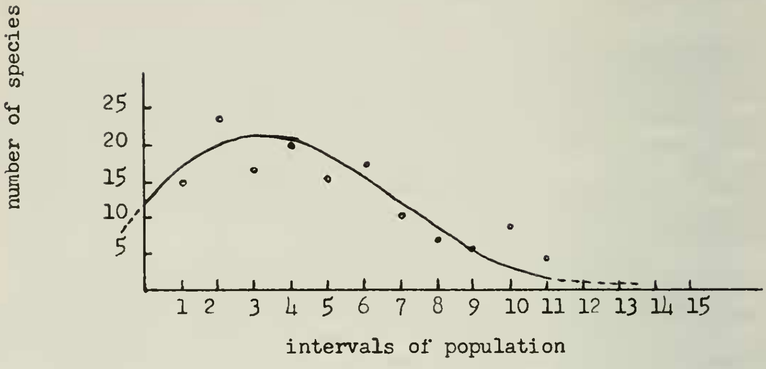

Figure 2 Truncated Normal Curve of Site B.

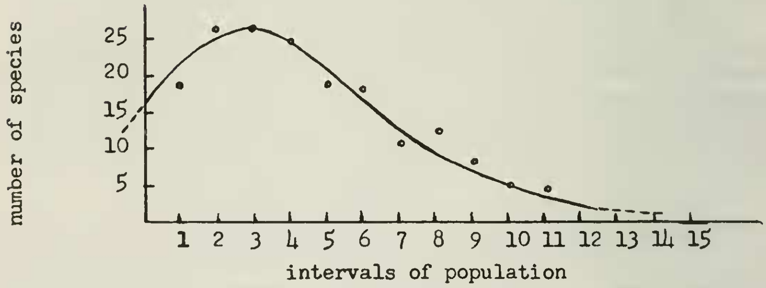

Figure 3 Truncated Normal Curve of Site C

rocks. *Spirogyra torta* Blum comprised the matt on the stream bed. At times strands of the *Spirogyra* broke from the matt and floated in the flowing water.

The recovery area, Site C, exhibited an extensive growth of the tetrasporacean species *Dispora crucigenioides* Printz. *Cladophora*, a genus common to alkaline waters (Whitford, 1969) also was abundant in Site C. Smith (1955) reported the occasional formation of *Cladophora* (*Aegagropila*) *holsatica* Kutz. into ball-shaped structures. Balls of this species to 0.5 cm in diameter were found growing on the floor of the concrete culvert where the highly alkaline water resulting from lime neutralization enters the stream directly above collection Site C. The force of the discharge water must act in forming the balls as wave action is thought to cause their formation in European lakes.

Table 1. lists the genera and species of diatoms according to site location and pH range. Characteristics from the literature, when available, are included (Lowe, 1970). A total of 22 genera and 129 species of diatoms were identified from the 3 collection sites.

Site A, the acid-polluted stream had 13 genera including 39 species. *Pinnularia* and *Navicula* exhibited greater diversity of species at Site A than other genera. Eighteen of the 39 species observed were isolated only from Site A. Five of these species were *Pinnularia*, and four were *Navicula*.

Site A is an environment under stress. The population is not typical of a hard acid stream but one under stress from a rapid environmental shift in a short distance and short time span. This is indicated by the drop in species diversity by one-half and the fact that one species, *Frustulia rhomboides*, represented 87 per cent of the total population. The biomass on the slides was scant and the diatom population slight. Such population structure occurs frequently in streams undergoing stress from low pH pollution as shown by Patrick (1973).

Site B displayed 19 genera and 67 species indicative of a "normal" slightly acid, soft water stream of the northeastern United States. The truncated normal curve developed as a mathematical model by Patrick et al (1954) at this site had the height of the mode at 21 with the curve covering 11 intervals (Fig. 2). The biomass on these slides was moderate and predictable from spring collections. The height of the mode is a little depressed and the tail of the curve is perhaps one interval long for a truly typical situation. This amount of deviation is bo be expected. Twenty-six of the 67 species were not present except at Site B. This particularly was true of species of *Cymbella* and *Nitzschia*. There was some indication of a chronic low level pollution at this site which could be from farm drainage, however, it might be just natural conditions.

Site C is located below where the non-polluted stream formerly merged before flowing toward Boyers, Pennsylvania. At present a holding lagoon prevents the acid-polluted water from entering the north branch (Fig. 1). During periods of heavy rain the channel

Table 1.

Diatoms isolated from selected sites of the North Branch of Slippery Rock Creek, Pennsylvania.

species	sites			descriptions
	B	A	C	
Achnanthes				
A. exigua var. *heterovalva* Krasska	X			oligosaprobe, littoral stream and lake form
A. hungarica (Grun) Grun. var. *hungarica*			X	B-mesosaprobe, standing or flowing water
A. lanceolata (Breb) Grun. var. *lanceolata*	X	X	X	oligosaprobe, rheophil, aerated flowing water
A. lanceolata var. *abbreviata* Reim.	X			
A. lanceolata var. *apiculata* Patr.			X	
A. lanceolata var. *dubia* Grun.	X	X	X	
A. linearis (W. Sm.) Grun. var *linearis*		X		
A. linearis f. *curta* H.L. Sm.		X		
A. microcephala (Kutz.) Grun. var. *microcephala*	X			current indifferent, pH unknown
A. minutissima Kutz. var. *minutissima*	X	X	X	oligosaprobe, ubiquitous diatom
Amphipleura				
A. pellucida Kutz. var. *pellucida*	X		X	oligosaprobe, littoral form
Amphora				
A. ovalis Kutz. var. *ovalis*			X	oligosaprobe
A. ovalis var. *pediculus* Kuta. Grun. in V.H.	X		X	mesosaprobe, epiphyts highly aerated water
Basillaria				
B. paradoxa Gmelin var. *paradoxa*	X			euryoxybiont
Cocconeis				
C. placentula var. *lineata* (Ehr) V.H.			X	oligosaprobe
Cyclotella				
C. meneghiniana Kutz. var. *meneghiniana*	X		X	euryombiont

Table 1. (continued)

	B	A	C	
Cymatopleura				
C. solea (Breb) W. Sm. var. solea	X			oligosaprobe, mesooxybiont, littoral form
Cymbella				
C. affinis Kutz. affinis	X		X	oligosaprobe
C. aspera (Ehr.) Cl. var. aspera		X	X	oligosaprobe, littoral form
C. cistula (Hemprich) Grun. var. cristula	X			oligosaprobe, epiphyte
C. cuspidata Kutz. var. cuspidata	X		X	saproxen, pH indifferent
C. gracilis (Rabh.) Cl. var. gracilis			X	
C. gracilis var. ???	X			
C. laeuis Naegli. var. laeuis	X		X	
C. lanceolata (Ehr.) V.H. var. lanceolata	X		X	oligosaprobe, littoral form
C. microcephala Grun. var. microcephala	X			B-mesosaprobe, current indifferent
C. naviculiformis Auerswald var. naviculiformis		X	X	oligosaprob, pH and current indifferent
C. prostata (Berkeley) Cl. var. prostata		X		oligosaprobe, rehophil
C. triangulum Grun. var. triangulum			X	
C. tumida (Breb). V.H. var. tumida		X	X	oligosaprobe, pH indifferent
C. tumidula Grun. var. tumidula	X			saproxen
C. turgida Grun. var. turgida	X		X	oligosaprobe, limnobiont
C. ventricosa Kutz. var. ventricosa	X		X	mesooxybiont, rheopholons, littoral form
Diploneis				
D. ovalis (Hilse) Cl. var. ovalis			X	saproxen
D. ovalis var. ???			X	
Eunotia				
E. arcus Ehr. var. arcus		X	X	saproxen, pH indifferent
E. arcus var. bidens Grun.			X	acidophil
E. curvata (Kutz) Lagerst var. curvata	X		X	

Table 1. (continued)

Eunotia	B	A	C	
E. exigua (Breb. ex Kutz.) Rabh. var. *exigua*	X	X	X	saproxin
E. major (W. Sm.) Rabh. var. *major*	X	X	X	
E. monodon Ehr. var. *monodon*	X	X	X	saproxin
E. pectinalis (Kutz.) Rabh. var. *pectinalis*	X			oligosaprobe
E. pectinalis var. *minor* (Kutz.) R.	X	X	X	current indifferent
E. perpusilla Grun. var. *perpusilla*			X	
Fragilaria				
F. construens (Ehr.) Grun. var. *construens*	X			oligosaprobe, littoral form
F. construens var. *venter* (Ehr.)Grun.		X		
Frustulia				
F. rhomboides (Ehr.) Det. var. *rhomboides*	X	X		saproxen, pH indifferent
F. rhomboides var. *amphipleuroides* (Grun) Cl.			X	
F. rhomboides var. saxonica (Rabh.) de Toni	X			
F. vulgaris (Thwaites) Det. var. *vulgaris*	X		X	oligosaprobe
Gomphonema				
G. constrictum var. *capitatum* (Ehr.) Cl.			X	
G. graciles var. *lanceolata* (Kutz.) Cl.			X	
G. intricatum Kutz. var. *intricatum*		X		
G. intricatum var. *vibrio* (Ehr.) Cl.			X	saproxen
G. intricatum var. ???	X			
G. parvulum Kutz. var. *parvulum*	X	X	X	pH indifferent, euryoxybiont,
G. parvulum var. *lanceolata*	X			

Table 1. (continued)

	B	A	C	
Gomphonema				
G. sphaerophorum Ehr. var. *sphaerophorum*		X		
Melosira				
M. varians Ag. var. *varians*			X	euryoxybiont, littoral form
Meridion				
M. circulare (Greu.) Ag. var. *circulare*		X		saproxen, rheophil
Navicula				
N. cryptocephala Kutz. var. *cryptocephala*	X		X	euryoxybiont, saprophyte
N. cryptocephala var. *veneta* (Kutz.) Rabh.		X		
N. cuspidata (Kutz.) var. *cuspidata*		X		
N. gregaria Donk. var. *gregaria*		X		
N. gysingensis Feged var. *gysingensis*			X	
N. integra (W. Sm.) Ralfs var. *integra*	X			mesooxybiont, rheophil
N. laevissima Kutz. var. *laevissima*			X	
N. lanceolata (Ag.) Kutz. var. *lanceolata*	X		X	saproxen, littoral and planktonic form
N. pupula var. *capitata* Hust.	X		X	mesooxybiont
N. pupula var. *elliptica* Hust.		X		
N. pupula var. *rectangularis* (Greg.) Grun			X	can stand more minerals than nominate variety
N. pusilla W. Sm. var. *pusilla*			X	aerophil, polyoxybiont
N. radiosa var. *tenella* (Breb. ex Kutz.) Grun.			X	oligosaprobe
N. rhynchocephala Kutz. var. *rhynchocephala*	X		X	mesooxybiont, littoral form
N. salinarum. var. *intermedia* (Grun.) Cl.			X	water of high mineral content
N. secreta var. *opiculata* Patr.			X	

Table 1. (continued)

Navicula	B	A	C	
N. viridata var. rostellata(Kutz) Cl.			X	mesooxybiont
Neidium				
N. affine var. longiceps (Greg.) Cl.			X	pH indifferent
N. iridis var. ampliatum (Ehr) Cl.			X	oligosaprobe, planktonic form
N. iridis var. ???	X			
Nitzschia				
N. amphibia Grun. var. amphibia		X	X	mesooxybiont, littoral form
N. denticula Grun. var. denticula	X			current indifferent
N. dissipata (Kutz) Grun. var. dissipata		X		mesooxybiont, rheophil
N. dissipata var. media (Kutz) Grun.	X		X	
N. frustulum (Kutz) Grun. var. frustulum	X			mesooxybiont, rheophil
N. gracilis Hantzsch var. gracilis	X		X	
N. obtusa var. scalpelliformis Grun	X		X	
N. pilum Hust. var. pilum			X	euryoxybiont
N. sigma (Kutz) W. Sm. var. sigma	X			mesooxybiont
N. sigmaodea (Nitz.) W. Sm. var. sigmaodea	X			oligosaprobe
N. spectabilis(Ehr.) Ralfs var. spectabilis			X	pH indifferent, oligosaprobe
N. tryblionella var. victoriae Grun			X	mesooxybiont
N. vermicularis (Kutz) W. Sm. var. vermicularis	X			oligosaprobe, rheobiontic
Pinnularia				
P. appendiculata (Ag.) Cl. var. appendiculata		X		
P. biceps Greg. var. biceps	X		X	circumneutral water
P. borealis Ehr. var. borealis		X		
P. braunii var. amphicephala (A. Moyer) Hust.		X		
P. hilseana Jan. var. hilseana		X		

Table 1. (continued)

Pinnularia	B	A	C	
P. mesogengyla Ehr. var. *mesogonygyla*			X	
P. mesolepta (Ehr.) W. Sm. var. *mesolepta*	X	X		oligosaprobe
P. microstauren (Ehr.) Cl. var. *microstauren*	X			oligosaprobe
P. nodosa (Ehr) W. Sm. var. *nodosa*			X	pH indifferent, oligosaprobe
P. ruttneria Hust. var. *ruttneria*	X		X	
P. subcapitata Greg. var. *subcapitata*		X		acidophil
P. viridis (Nitz.) Ehr. var. *viridis*			X	oligosaprobe, mesooxybiont
Stauroneis				
S. acuta var. *terryana* Temp. ex. Cl.	X			saproxen
S. anceps Ehr. *anceps*			X	pH indifferent, mesooxybiont, littoral
S. phoenicenteron f. *gracilis* (Ehr.)	X	X		pH indifferent
S. smithii Grun. var. *smithii*		X		
Suriella				
S. angustata Kutz var. *angustata*			X	euryoxybiont, rheobiont
S. elegans Ehr. var. *elegans*			X	saproxen, littoral form
S. linearlis var. *constricta* (Ehr) G.			X	oligosaprobe to saproxen, planktonic form
S. ovata Kutz. var. *ovata*	X		X	euryoxybiont, rheophil
S. ovata var. *pinnata* (W. Sm.) Hust.	X			
S. robusta Ehr. var. *robusta*			X	pH indifferent
Synedra				
S. pulchella Rolfs ex. Kutz var. *pulchella*	X		X	littoral form
S. rumpens var. *meneghiniana* Grun.	X		X	
S. rumpens var. ???		X	X	
S. ulna (Nitz) Ehr. var. *ulna*	X	X	X	mesosaprobe
S. ulna var. *clanica* (Kutz) V.H.	X			planktonic form
Tabellaria				
T. fenestrata (Lyngb.) Kutz. var. *fenestrata*			X	saproxen
T. flocculosa (Roth) Kutz. var. *flocculosa*	X		X	saproxen, acidophil

into the lagoon may overflow and some acid pollution enter the north branch. Due to this fact, Site C was selected below the overflow area and below where the lime neutralized acid-polluted water enters the stream. At point of entry the pH may be as high as 8.5 at times. Site C is 25 ft. below the plant.

Site C with its pH readings above 7 was represented by the greatest species diversity. The biomass on the slides was massive being from 20-25 times greater than the biomass on the slides from Site A. In this case the height of the mode in the normal truncated curve reached 26 but again in 11 intervals(Fig. 3). The species present (Table 1.) are indicative of a diatom population present in the lower recovery zone below a pollution area.

The 19 genera and 80 species isolated from Site C show a stream then recovering from stress. The eight species of *Navicula* indicate this. The *Nitzchia* present also tend to indicate organic pollution and a basic pH. *Navicula pupula* var. *rectangularis*(Greg) Grun and *N. salinarium* var. *intermedia* (Grun) Cl. also are species associated with water having a high mineral content. Thirty-seven of the 80 species were found only in Site C.

Twenty-eight species were common to both Site C and Site B. This was true of six species of *Cymbella*: *C. affinis* Jutz. var. *affinis*, *C. cuspidata* Kutz. var. *cuspidata*, *C. laeuis* Naegli var. *laeuis*, *C. lanceolata* (Ehr) V.H. var. *lanceolata*, *C. ventricosa* Kutz. var *ventricosa*, *C. turgida* Grun. var. *turgida*. Seven species appeared at both Site C and Site A. Three of these were species of *Cymbella*: *C. aspera* (Ehr) Cl. var. *aspera*, *C. naviculiformis* Auerswald var *naviculiformis*, *C. tumida* (Breb) var. *tumida*. Only nine of the 129 species occurred in all three environments. Most of these were either species of *Achnanthes* or *Eunotia*: *A. lanceolata* var. *dubia* Grun, *A. lanceolata* (Breb) Grun. *lanceolata*, *A. minutissima* Kutz var. *minutissima*; *E. exigua* (Breb ex Kutz) Babh. var. *exigua*, *E. major* (W. Sm.) Rabh. var *major*, *E. monodon* Ehr. var. *monodon*, *E. pectinalis* var. *minor* (Kutz) Rabh.

Both planktonic and littoral forms were well represented at all sites. Two epiphytes, *Amphora ovalis* var. *pediculus* (Kutz) in V.H. and *Cymbella cistuta* (Hemprich) Grun. were isolated from Sites C and A. Forms preferring both well aerated, swiftly-flowing water and indifferent current movements were represented at all three sites.

In conclusion this study of diatoms using species types, community structure, and slide biomass has shown that lime neutralization can be of value in helping a stream under stress from acid pollution to recover. A combination of diatom evidence from Site A shows a stream under great pH pollution stress while evaluation of Site B results indicates a "normal" ecologically healthy stream. The collected diatom information from Site C all points toward a stream well on its way to recovery. These results are in good agreement with other known chemical and biological parameters for the study area.

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